Tunnel Detection and Imaging: 2D and 3D Forward and Inverse Solvers

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It is of practical importance to detect, locate, characterize and image an underground object in subsurface sensing and geophysical exploration. In recent years, particular interests arising from homeland security needs call for underground tunnel detection capability. One of the most ambitious methods to develop such detecting techniques is to cast it into an inverse scattering problem governed by electromagnetic wave equations with the goal of providing a high-resolution image in spatial and physical parameters of the objects. In this work, we developed fast 2D and 3D forward and inverse solvers for a layered medium based on the volume electric field integral equations and applied them to tunnel detection and imaging.

These forward and inverse solvers combine BICGSTAB(L) algorithm, FFT, diagonal tensor approximation (DTA), and contrast source inversion (CSI) techniques for the purpose of tunnel detection. The layered-medium Green's functions are used to formulate 2D and 3D volume integral equations. For the 3D layered-medium dyadic Green's function, a compact representation is given based on scattering superposition of the field in the spatial domain, in which all components of the dyadic Green's function are expressed as combinations of a few basic Sommerfeld integrals and calculated recursively. The BICGSTAB(L) algorithm is combined with FFT to accelerate the solution of the integral equations. The diagonal tensor approximation is investigated in the acceleration of full nonlinear CSI inverse solver for layered media.

A number of examples will be presented to validate the effectiveness and capacity of 2D and 3D forward and inverse solvers. Tunnels under different geophysical environments are simulated and reconstructed. Tunnel imaging with various transmitting and receiving arrays as well as different operating frequencies is also investigated to determine optimal measurement configurations. Some results of interest are observed and discussed. It has been shown that high-quality image reconstruction of straight and curved tunnels, complicated buildings of arbitrary shape, as well as men-like objects in the tunnel can be achieved with the developed layered-medium forward and inverse solvers.